SEAI Project RDD/00104 Project Report

Ambigas: Technical Progress; Market Research & Commercialisation Activities

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TABLE OF CONTENTS

Executive Summary (Project Completion Summary Report)

The novel Low temperature Anaerobic Digestion (hereafter referred to as Lt-AD) wastewater (WW) treatment technology was assessed during the course of this SEAI Ambigas project from: (i) a technical perspective in terms of laboratory and pilot-scale trials on the prototype bioreactor design; and (ii) from a commercial perspective to identify target markets and regions, as well as additional sectors, which would benefit from the technique into the future. The Food & Drink industrial sectors of Milk Treatment & Processing and Brewing & Distilling are the main focus markets of this report due to reasons such as:

(a) Significant global market for these sectors,
(b) Operations at these sectors' operations generate significant quantities of WW requiring treatment prior to discharge,
(c) AD being an accepted, proven technology for industrial WW treatment in many areas of the world and thus the introduction of a more advanced AD treatment technology would be seen as an operational advantage,
(d) The continued promotion of AD technologies by bodies such as the Environmental Protection Agency (EPA) and relevant guidances such as the BAT (Best Available Techniques) documentation, which identifies AD as a recommended treatment technology for both of the target sectors.

Market analysis of both sectors indicates that they are showing signs of increased production. It has been reported that by 2014 the global beer market returned a 5% increase in production on the 2009 figure, and the Brewing & Distilling industry is one that generates significant quantities of WW requiring treatment prior to discharge. This sector is one that would greatly benefit from a cost-effective, sustainable WW treatment technology which generates little to no sludge requiring further treatment and disposal. Even more promising to the Lt-AD technology is the Milk Treatment & Processing sector, whose advancement is directly related to economic growth in the emerging economies. Increasing demand from Asian countries in particular is placing a strain on demand for Dairy products, and Ireland with its long tradition of Milk Treatment & Processing and availability of land space is significantly increasing output to accommodate rising demands of a world with an increasing population. The phasing out of the milk quotas is having, and will continue to have, a profound effect on dairy production in this country and in turn will result in escalating quantities of WW requiring sustainable treatment.

The target sectors in the UK show interesting trends. For instance the UK Brewing & Distilling industry has changed dramatically in the past 30 years and the market is now dominated by micro-breweries, with the larger producers such as Carlsberg and Heineken reducing the number of plants they operate. Although it is these larger producers who are the target customers of the Lt-AD WW treatment technology, there is still a significant market for Lt-AD in the UK and AD technology is an accepted practice for Brewing & Distilling as its variable WW composition warrants the use of AD and the generation of a biogas is a bonus to the users. It may turn out to be the case that the Milk Treatment & Processing sector in the UK (and Ireland) will be that targeted initially by the Lt-AD technology. In the UK, the sector is dominated by larger producers who are crippled with escalating trade effluent charges by private water companies treating their effluent. Tightening of EU legislation such as the Water Framework Directive (WFD), etc. for effluent release is likely to bring increased investment in sustainable technologies for industrial WW treatment. Additionally, legislation to enhance the uptake of AD for WW treatment in Europe is plentiful and most member states have initiated their own incentives to aid in the uptake. The UK has established significant incentives such as Feed in Tariffs etc. to encourage AD treatment of WW, and the Irish government operates a REFIT scheme for promotion.

The use of AD has the potential to aid Ireland and the UK with meeting a number of important commitments and targets including those set out in the Climate Change Act and the EU's binding targets for renewable energy which is proposed to be 15% and 16% by 2020 for the UK and Ireland respectively. In Ireland, there has been significant effort put into the promotion of wind as a renewable energy source, however wind can be an unpredictable resource, unlike AD which is quantifiable source of renewable energy. It was recently announced that the combination of AD and wind based energy could supply 40% of Ireland's electricity needs by 2020 (The Development of Anaerobic Digestion in Ireland, Jan. 2011). European incentives for the treatment of WW using AD do not appear to have been imitated in the US, where energy prices are still relatively low and where few industries treat their WW to any great extent prior to release to municipal treatment facilities. However, this situation appears to be changing with reports on the benefits of AD for WW treatment being published (McCarty, et al., 2011).

As regards alternative target markets for Lt-AD, i.e. municipal WW treatment - Ireland and the US are generally using aerobic treatment technologies to treat WW and in the process are generating significant quantities of sludge requiring dewatering, treatment and disposal. Despite the global economic downturn, each member state has obligations to the EU to improve WW treatment standards; however it seems that most of the investment appears to be in upgrading existing WWTPs, rather than building new facilities. In the US, future investment trends will be for enhancement of plants' design capacity to provide greater than secondary treatment. Lt-AD may be a retrofit option for such investments as it is not only a superior treatment technology but it is estimated to generate 50% less sludge compared to conventional mesophilic AD, and 90% less sludge compared to aerobic treatment (based on laboratory trials and initial on-site studies). This alone is a valuable feature considering that in Asia, municipal sludge quantities are estimated to be 8.05 million tonnes by 2020 and AD has been proposed to be utilised in medium-to large WWTPs in China. Sludge quantities are a pressing issue for everyone; in fact a recent US EPA report stated that ~8.2 million dry tonnes of sludge would be generated in 2010 alone, which is estimated to cost the US government over €2 billion in treatment and disposal costs (based on a sludge treatment and disposal figure of approximately €250/dry tonne in Europe). Municipal WW treatment in Ireland and the US is predominately Government-run and as a result this may be a difficult market to target at present due to the current economic downturn, however increasing pressure to improve standards of treatment may be more effective in bringing in a new technology such as Lt-AD. In the UK, private water companies are responsible for the treatment of WW however global economic issues seem to have also led to limited investment in new builds in the short to medium term.

A market which the Lt-AD technology plans to target in the longer term is the Pharmaceutical industry. Preliminary analysis of the Irish market has shown that there were (as of July 2012) twenty eight plants holding current IPPC licences, the majority of which elute their effluent streams to the sewer. It was found that approximately 67% of the plants treat their own WW on-site to secondary treatment standard prior to discharge; with ~22% performing only preliminary treatment of effluent - such treatment usually involves just equalisation and pH adjustment. Aerobic treatment is the most commonly used on-site WWT technique where the sludge generated is dried to a suitable level and then incinerated either on-site or at an off-site location. This market would be a good focus for the Lt-AD technology due to the significant economic success of the industrial sector at present, and the fact that Ireland is a hub for large, multi- national pharmaceutical industries.

Introduction

NUI, Galway completed project activities as set out in the Ambigas project grant RDD/000104, awarded to Prof. Vincent O'Flaherty of NUI, Galway (hereafter referred to as NUIG) by SEAI. This report represents D4- *"Project Report Underpinning Future Commercialisation".* Three other project deliverables were identified:

D1: "An extensive database of potential industry end-users based on both direct contacts and publically available information from the EPA IPPC licences, will be carried out. "

This is completed in full for the Irish market and a representative selection from the UK market has also been compiled. This information is introduced in **Appendix 2** and appended in the form of excel spread sheet along with this submission (**Appendix 1a-1d**). A synopsis of the information compiled is provided in the "Potential Industrial End-Users Information" section, which follows.

D2: "*Process dataset at laboratory and pilot-scale to confirm assumptions and to provide model to allow completion of D3*." The data is summarised in **Appendix 3**.

D3. "Potential suppliers of full-scale plants and associated equipment will be sought and full-scale plant costs and potential commercial relationships will be developed."

A list of potential suppliers for all equipment relevant for a full-scale plant set-up has been compiled and relationships developed. Information regarding estimated costings and set-up required for a full-scale plant is presented in the "Full-Scale Plant Set-Up Information" section of this report.

The specific advantages of the system over competing technologies is presented in **Appendix 3** and advantages in terms of CAPEX, OPEX and sludge reduction for a retrofit situation is presented in in the "Full-Scale Plant Set-Up Information" section of this report. Information on the competing technologies currently used in each of target industries is presented in the spread sheets referenced in **Appendix 1**, and in the "Potential Industrial End-Users Information" section which follows.

Potential Industrial End-Users Information

"An extensive database of potential industry end-users based on both direct contacts and publically available information from the EPA IPPC licences, will be carried out. "

Irish Market

The LtAD technology is directed towards low-strength wastewater (WW) of the type generally produced from the Food & Drink industries, as specified in the proposal. Information relating to potential end-users was gathered from both direct contacts and the published information from the EPA Integrated Pollution Prevention Control (IPPC) licences.

Currently, there are ninety-seven IPPC licences listed on the EPA website under the Food & Drink industry umbrella, which can be further divided into the following sectors:

1. Brewing & Distilling (ten existing licences)
2. Slaughterhouse (forty-three existing licences)
3. Rendering animal by-products (seven existing licences)
4. Disposal/recycling of animal waste (three existing licences)
5. Food Production (eleven existing licences)
6. Manufacture of Dairy Products (four existing licences)
7. Manufacture of Fish-meal/-oil (one existing licence)
8. Milk Treatment & Processing (eighteen licences)

Initially, all sectors listed above were assessed for suitability to the LtAD technology. Such an assessment involved gathering information on the treated WW emission limits each industry currently needs to adhere to (see **Appendix 1** and relevant excel spread sheet), according to their IPPC licences. Such information is imperative to defining LtAD target industries, as in many facilities only neutralisation and equalisation occurs prior to sewer release. As a result, the characteristics of the WW released provides a very good insight into the characteristics of the raw effluent. Also, the limits for release from the IPPC licences are a good indication of the WW characteristics.

Following this assessment on all eight industrial sectors as specified above, more detailed investigation was concentrated on suitably deemed divisions. The sectors which were eliminated from relevance to the LtAD technology were:

1. Disposal/recycling of animal waste
2. Rendering animal by-products
3. Slaughterhouse

Whereas, the sectors of relevance to LtAD were deemed to be:

1. Brewing & Distilling
2. Milk Treatment & processing
3. Food Production
4. Manufacture of Dairy Products
5. Manufacture of Fish-meal/-oil

In relation to the LtAD relevant sectors specified above, further information relating to the characteristics of the generated WW (pre-treatment) as well as the currently used methods of treatment (aerobic or anaerobic) was researched and is presented in **Appendix 1**, and a synopsis is provided in the pages which follow for each individual sector. A short literature review of WW characteristics for the relevant sectors was generated and is presented in **Appendix 2**. In combination, the compiled information on: currently used WW treatment methods, issues being experienced by users with the currently used techniques and the fate of the resultant sludge produced, provides an extensive database of relevant potential end-users for the novel LtAD technology.

Brewing & Distilling

It was found that the majority of effluent streams from this sector are eluted to the sewer for treatment at a central wastewater treatment plant (WWTP), run by the relevant local authorities. As a result, on-site treatment facilities are limited with only quite a few offering preliminary treatment (equalisation and balancing) prior to release. If on-site treatment is carried out, aerobic treatment is the most commonly used technique, with the sludge generated being eventually land-spread in most cases.

A synopsis of relevant information on each of the Brewing & Distilling industries is provided in **Table 1**.

Table 1: Brewing & Distilling WWTP Information and Potential End-Users

Brewing & Distilling Industries	WWTP on-site ?	WWTP & characteristics
Cooley Distillery PLC	√ Aerobic treatment	WWTP capacity: 12 m^3/hour (BOD 3,000 mg/L); Licence max. release: 400m^3/day; 18 m^3/hour
Cherries Breweries Ltd. (trading as the Waterford Brewery)	X Consideration to be given to AD	530m^3/day WW released to sewer(365 days/year). Licence emission limit: 1,510m^3/day
E. Smithwick & Sons Ltd.	X (only pH balancing)	Effluent loading to sewer: 2700m^3/day (527,557m^3/year); Licence emission limit: 988,200m^3/year
Heineken Ireland Ltd.	X	Approx. 10,000m^3/day effluent released; Licence limit emissions: 1,800 m^3/day (200 m^3/hour)
Bulmers Ltd.	No information provided	Licence effluent release max. volumes: 200m^3/day & 30m^3/hour
Bulmers Ltd.	√ Aerobic treatment (2005) with upgrading to include EGSB AD pre-treatment step (2006)	2005 capacity: 1560m^3/day; 2009 future capacity: 2674m^3/day [COD loading 5,300kg/day (2005) & of 18,115kg/day (2009)].
Irish Distillers Ltd.	√ Little detail provided but thought to be aerobic	A new WWTP was commissioned in Jan 2005 with design capacity of 1250 m^3/day; licence max. limit: 5,000m^3/day & 270m^3/hour
Diageo Ireland Ltd. t/a The Great Northern Brewery	X (only pH neutralisation)	Average brewery load (1998): Dry weather flow (m^3/day): 1,100; Licence max. release: 2,000m^3/day & 235m^3/hour
Beamish & Crawford PLC (now closed)	X	Average released to sewer: 1,204m^3/day (2007), 1095m^3/day (2008) & 445m^3/day (2009); licence limit: 3,000m^3/day (300m^3/hour)
Diageo Ireland	X (only equalisation & neutralisation)	Three emissions to sewer from plant in 2009 (limits): 1. 956,429m^3/year (2,737,500m^3/year), 2. 58,726m^3/year (438,000 m^3/year), 3. 1,194m^3/year (401,500m^3/year); Max. licence release: 1. 7,500m^3/day, 2. 1,200m^3/day, 3. 1,100m^3/day

It is interesting to note that in situations where plants have no treatment on-site (e.g. Cherry's brewery Ltd.), the EPA requested that applicants investigate the possibility of on-site treatment of trade effluents with special attention to be paid to anaerobic digestion (AD). It is also stated that "the anaerobic digestion process is particularly suited to brewery effluent due to the relatively high BOD concentrations and the potential for on-site use of generated biogas as boiler fuel." This promotion of AD for the Brewing & Distilling sector is causing AD to be adopted into Irish industries, for example as part of Bulmers' expansion in 2006, an EGSB anaerobic digester was incorporated into their on-site WWTP.

When aerobic and conventional anaerobic processes are utilised for WW treatment, sludge storage facilities must be available on-site which leads to additional capital costs for the sludge being continuously generated to be housed for at least four months of the year. The practice of land-spreading is only carried out for eight months of the year, so either the sludge being generated is housed in sheds for four months or it must be treated using alternative techniques (composting, thermal treatment) which leads to a higher cost for the industry.

Food Production

The food production sector in Ireland incorporates a wide range of different industries which fall under the following criteria: manufacture of sugar (Irish Sugar PLC), treatment or processes for the purposes of the production of food products from - (a) animal raw materials (other than milk), (b) vegetable raw materials (AIBP t/a Silvercrest Foods, Cadbury, Dunbia, Arrow Group, Green Isle, Duffy Metals Ltd., Rye Valley Foods, R&A Bailey & Co.).

In a similar manner to that for the Brewing & Distilling, it was found that the majority of effluent streams from the food production sector are eluted to sewers. As a result, on-site treatment facilities are limited with many only offering preliminary treatment (equalisation and balancing) prior to release. Otherwise, aerobic treatment of WW is the technique most commonly used and the sludge generated is either land-spread or rendered. Quite a few plants currently require up-grading of their systems and all details are provided in the spread sheets included in this report and referenced in **Appendix 1**.

A synopsis of relevant information on each of the food production industries is provided in **Table 2**.

Table 2: Food Production WWTP Information & Potential End-Users

Food Production Industries	WWTP on-site ?	WWTP & characteristics
Dunbia (Ireland)	× No WWTP on-site (only screening & fat-trap)	Max. daily flow to sewer (no WWT on-site & based on the max. hourly flow limit $4m^3$/hour) is $96m^3$/day
Green Isle Foods Ltd.	√ Aerobic treatment	The effluent treatment plant holds 3.6million litres within its tanks at any one time. Max. flow from WWTP to sewer: $36m^3$/hour or $864m^3$/day
Arrow Group Ltd.	√ Aerobic treatment	WW is generated on-site at a rate of approx. $600m^3$/day from manufacturing activities. Max. discharge from WWTP is $800m^3$/day & $40m^3$/hour
Cadbury Ireland Ltd.	√ Biological aerated filter treatment	Flow from the WWTP to sewer is generally $<300m^3$/day
R&A Bailey & Co.	× (only pH neutralisation & balancing)	The average volume of effluent discharged to the municipal system is 400 m^3/day
Rye Valley Foods Ltd.	√ Primary aerobic treatment	Flow of $650m^3$/day over 275 days/year
Green Isle Foods Ltd.	√ Physico-chemical process, no biological treatment on-site.	Emissions from WWTP to sewer: Max. $420m^3$/day; Normal: $310m^3$/day & Max.: $73m^3$/hour
Duffy Meats Ltd. (trading as Kerry Foods)	√ Aerobic treatment	Max. volume effluent released to sewer: $750m^3$/day ($32m^3$/hour); Volume untreated effluent produced: $680m^3$/day
AIBP t/a Silvercrest Foods	× Only details provided are that there is a DAF unit present	Volume eluted in 2009: $19,229m^3$ ($53m^3$/day); Daily discharge volume to sewer of $100m^3$ ($365,000m^3$/year)
Irish Sugar PLC (Cork)	√ Aerobic treatment	Proposed modification to WWTP would provide capacity: $6,100m^3$; Max. licence release: 50,400 m^3/day & 2100 m^3/hour

Manufacture of Dairy Products

The information provided for this sector was found to be limited - very few details were provided for the WWT facilities available on-site. It seems that effluent release in all cases is to surface water bodies such as rivers and lakes, thus significant WWT must occur prior to release. The predominantly used WWT technique is aerobic (activated sludge), and the resultant sludge is either land-spread or composted.

A synopsis of relevant information on each of the Dairy Products Manufacturing industries is provided in **Table 3**.

Table 3: Dairy Products Manufacturing WWTP Information and Potential End-Users

Manufacture of Dairy Products Industries	WWTP on-site ?	WWTP & characteristics
Abbott Ireland	√ Primary & secondary aerobic treatment (activated sludge)	The permitted volume to be emitted: 2000m^3/day & 83m^3/hour; The additional anticipated loading for will be in the range of 1200m^3/day i.e. 3200m^3/day
Glanbia Ingredients (Virginia) Ltd.	No details provided	Discharge of treated effluent: 1,400 m^3/day
Dairygold Co-op Society Ltd.	√ Aerobic treatment (activated sludge)	Emission of treated effluent to receiving waters: 4,500m^3/day (200m^3/hour)
AHP Manufacturing B.V. t/a Wyeth Nutritionals Ireland	√ Aerobic treatment (activated sludge)	Max. release: 2,800m^3/day (126m^3/hour); Total balance tank volume is ~1,800m^3 and total SBR volume is 5,000m^3

Manufacture of Fish-meal/-oil

Only one industry in this sector was registered on the EPA website, i.e. United Fish Industries Ltd located in Donegal. Recent Donegal County Council correspondence to the company wanted to ensure that the fish processing industry would treat its own WW to secondary treatment standard prior to discharge to the sewer. Currently, the industry screens and pre-neutralises their process effluent prior to treatment in the Dissolved Air Flotation (DAF) unit. The company installed trial units of a MEVA step filtration and belt filters to reduce the load being treated in the DAF plant. Installation of an Electro-flocculation unit to polish DAF effluent was also installed.

Unfortunately no data is published for pre-treated WW, only post-treatment WW using the techniques described in preceding paragraph.

Milk Treatment & Processing

The vast majority of industries in this sector were found to operate aerobic (activated sludge) WWT and effluent is released to surface water such as rivers and lakes. Two industries use AD technologies (Kerry and Carberry), but in both cases post-activated sludge processes are also carried out. It was reported that Dairygold planned to install an anaerobic digester (EPA report April 2007) as pre-treatment for effluent – it was stated that this would remove 70 – 75% of the BOD from the effluent, and decrease sludge production by about 60%, consequently significantly reducing energy requirements for aeration.

Sludge is generated in the case of all industries investigated and the vast majority of sludge is land-spread, however in one case sludge is also composted and in another it is rendered.

Expenditure on WWT is provided in one case i.e. Glanbia (Ballyragget) spent the following amounts on WWT between 2001-2003: Effluent treatment: €3,350,603; Sludge storage: €600,000. Since then their WWTP has been up-graded to provide additional balancing capacity (4040 m^3), nutrient removal through the provision of an anoxic tank (2,000 m^3), a new Krofta DAF pre-balance tank together with modifications to the clarifier.

A synopsis of relevant information on each of the milk treatment and processing industries is provided in **Table 4**.

Table 4: Milk Treatment & Processing WWTP Information and Potential End-Users

Milk Treatment & Processing Industries	WWTP on-site ?	WWTP & characteristics
Town of Monaghan Co-op.	√ Aerobic treatment (activated sludge)	Max. discharge of final effluent: 820m^3/day (45m^3/hour) - normal: 590m^3/day; condensate discharge: 300m^3/day (65m^3/hour)
Glanbia Foods Society Ltd.	√ Aerobic treatment	Process effluent released post-treatment: 600m^3/day
Shannonside Milk Products Ltd.	√ Aerobic treatment	Plant capacity: 5,000kg BOD/day; Max. flow rate: 2,100m^3/day
Tipperary Co-op. Creamery Ltd.	√ Aerobic treatment (activated sludge)	Max. discharge rate: 792-696m^3/day (29-32m^3/hour) from WWTP to river
Lakeland Dairies Co-op. Societies Ltd.	√ Aerobic treatment	Volume effluent released to WWTP: ~309,400m^3/year Discharge flow requirement for final effluent: 2000m^3/day or 125m^3/hour (60m/hour; 24hs/day; 275day/year). In the summer-time, throughput of WWTP would average at ~1000 m^3 with a max. throughput of ~ 1400m^3
Glanbia Foods Society Ltd.	× (only balancing & pH neutralisation)	Max. output to sewer: 600m^3/day (50m^3/hour); Av. daily rate/week: 450m^3
Lakeland Dairies Co-op. Society Limited t/a Lakeland Dairies Drying Plant	√ Aerobic treatment	Daily flow rate: 2000m^3/day; Discharge limits: 1,500m^3/day (max. 80m^3/hour)
Cadbury Ireland Ltd.	√ Aerobic treatment	Discharge limits: 900m^3/day (max. 40m^3/hour) - periods of emission: 60min/hour; 24hour/day; 365day/year; Typical daily flows: 560m^3/day (2006)
Wexford Creamery Ltd.	√ Aerobic treatment	Average influent flow: 1000 m^3/day to the WWTP; Max. licence: 1,600m^3/day (100m^3/hour)
Newmarket Co-Op. Creameries Ltd.	√ Aerobic treatment (activated sludge)	Balance tank capacity: 1362m^3; current discharge from WWTP: 725 m^3/day (proposed discharge: 1000 m^3/day or 60m^3/hour - 60mins/hour, 24hour/day, 365 days/year)
Nutricia Infant Nutrition Ltd.	√ Aerobic treatment (activated sludge)	Existing WWTP is designed to treat ~ 1,363 m^3/day. It is proposed to upgrade WWTP to be capable of treating 2400 m^3/day to a level of 10 mg/l BOD and 25mg/l SS. Max. discharge: 1500m^3/day. The company plan to upgrade the WWTP in order to cope with increased processing and to discharge 2400m^3/day effluent (60mins/hour: 24hour/day, 365 days/year)

Table 4 (continued): Milk Treatment & Processing WWTP Information and Potential End-Users

Milk Treatment & Processing Industries	WWTP on-site ?	WWTP & characteristics
Arrabawn Co-operative Society Ltd.	√ Aerobic treatment (activated sludge & biofiltration)	WWTP discharge: 1,364m^3/day; Arrabawn have applied for an increase in the permitted discharge from 1,364 m^3/day to 2,271 m^3/day (60mins/hour, 24hour/day, 365 days/year)
Bailieboro Foods Ltd. & Bailie Foods Ireland Ltd.	√ Aerobic treatment (activated sludge)	The WWTP has capacity to treat up to 800m^3/day; Max. daily release limits: 650m^3/day & 35m^3/hour
Dairygold Co-operative Society Ltd.	√ Aerobic treatment (activated sludge). Plan to install an AD (EPA report April 2007) for effluent pre-treatment	An increase in the daily process effluent volume limit from: 8,900m^3 to 10,000m^3
Kerry Ingredients (Ireland) Ltd.	√ Anaerobic treatment & activated sludge	Max. licence release: 10,000-12,000m^3/day (416-500m^3/hour); Actual emission (2009): 2,382,430m^3/year vs. emission limit (2009): 3,956,000m^3/year
Carberry Milk Products Ltd.	√ Anaerobic treatment & activated sludge	Max. emission: 4,000-6,000m^3/day; 216-250m^3/hour
Kerry Ingredients (Ireland) Ltd.	√ Aerobic treatment	WWTP balance tank capacity: 2,453m^3; six storage lagoons (total capacity: 600,000 m^3); Peak daily flow to WWTP: 4,023m^3; Max. release limits: 18,000m^3/day (750m^3/hour)
Glanbia Ingredients (Ballyragget) Ltd.	√ Aerobic treatment	WWTP is being up-graded to provide additional balancing capacity (4040 m^3). Max. emission limits for final effluent from WWTP: 12,000m^3/day (500m^3/hour)

In many cases, EPA documentation details the WWTP processes occurring on-site in the form of flow-charts, and additional detailed information was also gathered from contacts in the Dairy Processing industry. Flow charts which detail the exact layout, as well as the dimensions of the tanks or units are particularly useful as they provide an insight into the capacity required for design of an alternative LtAD WWT system. In addition, such details give a clear indication as to the financial implications for the retrofit of current systems with the LtAD alternative technology. Lakeland Dairies, Cavan – a Milk Treatment & Processing plant - was used as a case study and information relating to the plant's current WWT process, CAPEX, OPEX and savings if retrofitted using the LtAD design are presented in in the "Full Scale Plant Set-Up Information" section of this report.

UK Market

A representative sample of UK Food & Drink industries operating under the following sectors: Brewing & Distilling and Milk Treatment & Processing, were selected for analysis of their WWT processes. A detailed spread sheet of potential users, currently used processes as well as WW and effluent characteristics is provided and referred to in **Appendix 1**.

Brewing & Distilling

It was found that the majority of effluent streams from this sector are eluted to the sewer for treatment at a central WWTP. As a result, on-site treatment facilities are limited with only a few offering preliminary treatment (equalisation and balancing) prior to release. In cases where on-site treatment is carried out, AD is the most commonly used technique. Sludge disposal methods were not outlined in any of the cases investigated.

A synopsis of relevant information on each of the Brewing & Distilling industries analysed is provided in **Table 5**.

Table 5: Brewing & Distilling WWTP Information and Potential End-Users

Brewing and Distilling Industries	WWTP Details and WW Characteristics
Heineken UK (Royal Brewery, Manchester) – WWTP operated by Veolia	AD and aerobic treatment, prior to tertiary treatment; Flow Rates – 95 m^3/hour
Heineken UK (Bulmers Cider Mills)	No details of on-site treatment provided; WW discharged to sewer
Inbev UK Ltd. (Magor Brewery)	Wastewater treated on-site using UASB AD technology
Inbev UK Ltd. (Samlesbury Brewery)	pH neutralisation of the effluent takes place before discharge to sewer. No other WWT processes are undertaken on-site
Inbev UK Ltd. (Budweiser Brewing Co.)	WW discharged to sewer
Coors UK (Alton Brewery)	pH neutralisation of the effluent takes place before discharge to sewer. No other WWT processes are undertaken on-site
Coors UK (Burton Brewery)	WW discharged to sewer. No details of on-site treatment provided
Coors UK (Tower Brewery, Tadcaster)	Screening, Balance Tanks and Divert Tanks, AD, Aerobic Post-treatment, DAF and Disc Filter; Flow Rate - 1323 m^3/day
Diageo Distilling Ltd. (Cameronbridge)	Mesophillic AD and post aeration is carried out on-site

Milk Treatment & Processing

It was found that the majority of effluent streams from this sector are eluted to the sewer for treatment at a central WWTP. As a result, on-site treatment facilities are limited with only quite a few offering preliminary treatment (pH neutralisation and screening) prior to release.

A synopsis of relevant information on each of the Milk Treatment & Processing industries analysed is provided in **Table 6**.

Table 6: Milk Treatment & Processing WWTP Information and Potential End-Users

Milk Treatment & Processing Industries	WWTP on-site and Characteristics
Wiseman and Sons - Droitwich Dairy	Measuring, monitoring and chemical dosing of effluent prior to discharge; Flow rate – 948 m^3/day
Wiseman and Sons - Trafford Park Dairy	No WWTP on-site; WW is discharged to sewer; Flow rate – 600m^3/day
Wiseman and Sons - East Kilbryde, Strathclyde	WW is discharged to sewer; no details of on-site WWT provided
Wiseman and Sons - Bridgewater	DAF unit and Membrane Bioreactor on site.
Wiseman and Sons - Lanarkshire	WW is discharged to sewer; no details of on-site WWT provided
Arla Foods Ltd - Ashby de la Zouch	pH adjustment, screening, DAF, addition of organic chemicals is carried out to ensure good separation and reduction in SS and COD, carbon filters are used on the DAF unit to reduce odours
Arla Foods Ltd - Stourton Pontefract Road	Effluent Balance Tanks, pH Neutralisation and Membrane filtration occur prior to release; sludge produced from the WW treatment process is land spread
Arla Foods Ltd - Oakthorpe, London	WW is discharged to sewer; no details of on-site WWT provided
Dairy Crest Ltd - Selinas Lane, Essex	WW is discharged to sewer; no details of on-site WWT provided
Dairy Crest Ltd - Foston	Reception and screening of raw effluent, DAF unit clarification, biological treatment, waste sludge separation/storage for transport off-site is carried out prior to discharge to sewer
Dairy Crest Ltd - Snakey Lane	WW is discharged to sewer; no details of on-site WWT provided
Dairy Crest Ltd - Aintree, Liverpool Dairy	No WWTP on-site: effluent is captured, monitored and discharged to sewer
Dairy Crest Ltd - Oldends Lane, Gloucester	WW is discharged to sewer; no details of on-site WWT provided
Milk Link - Llandyrnog Creamery	WW is discharged to sewer; no details of on-site WWT provided

Full-Scale Plant Set-Up Information

"Potential suppliers of full-scale plants and associated equipment will be sought and full-scale plant costs and potential commercial relationships will be developed."

Potential suppliers of all equipment required for full-scale LtAD plant set-up was compiled and is presented therein. Relationships with the PI, his research group and potential LtAD unit manufacturers were developed during Stage 1 of this research project. The NUIG research group held meetings with accomplished Irish manufacturers (Kells Stainless, Spectac Ltd. and Spectrum Tooling Ltd.) to discuss the specifications and requirements of the LtAD unit at both pilot and full-scale plant level. In addition, NUIG held in-depth discussions with potential suppliers of other critical components for full-scale plants, i.e. gas phase monitoring equipment, pumping solutions, piping providers, etc. in order to formulate a comprehensive picture of a full-scale LtAD WWTP. From such discussions a flow chart of a full-scale LtAD WWTP for the treatment of the two WW types proposed in the grant: (a) municipal and (b) industrial (Food & Drink), was formulated. An estimate of pricing and a schematic representation of a full-scale LtAD plant and associated equipment are provided in the pages which follow. Such an estimate was compiled following discussions with the potential suppliers and manufacturers detailed in the following pages. The LtAD system may also be incorporated into existing WWTPs by retrofitting and this alternative scenario is also presented.

It needs to be mentioned that at this early stage it is difficult to estimate the entire full-scale costings for a universal LtAD WWTP for treatment of all Food & Drink industry and/or municipal WW. Considerations such as: WW characteristics, space constraints on-site, civil works required, the possibility of retrofit and the required quality of the resultant effluent etc. would all need in-depth investigation on a site-by-site basis. As a result no price estimates for civil engineering works and project management are included in this estimation as these would be site-specific and are difficult to assess at this early stage. However, the CAPEX and flow-chart schematic presented herein are good indications of the key component requirements to produce WW of sufficient standard for final release.

Potential Suppliers of Full-Scale LtAD Plants

The set-up of a full-scale LtAD WWTP will require ground works and excavations to be carried out. **Table 7** outlines some Irish contractors who have experience in the area of large scale WWTP construction.

Table 7: Potential Civil Engineering Works Contractors for Full-Scale LtAD Installations

Civil Engineering Works Contractors		
Company	**Expertise**	**Location**
Kilcawley Construction	WW Civil Works	Sligo, Ireland
Coffey Group	WW Civil Works	Galway, Ireland
Jennings O'Donovan & Partners	WW Civil Works	Sligo, Ireland
Lagan Construction Ltd.	WW Civil Works	Dublin, Ireland

Preliminary treatment of WW is required in order to prevent large particles entering pumps and treatment vessels. Potential suppliers for preliminary treatment equipment are outlined in **Table 8.**

Table 8: Potential Suppliers for Preliminary Treatment Systems

Preliminary WW Treatment		
Company	**Expertise**	**Location**
EPS	WWT Products	Cork, Ireland
JWS International	WWT Products	UK
Treatment Systems Ltd.	WWT Products	Kilkenny, Ireland

The LtAD reactor vessel will be constructed from stainless steel. The potential suppliers outlined in **Table 9** have been chosen with consideration of their ability to construct full-scale LtAD reactors for multiple sites.

Table 9: Potential Manufacturers of Full-Scale LtAD Reactors

Reactor Manufacture		
Company	**Expertise**	**Location**
Kells Stainless	Design & Manufacture Customised Vessels	Kells, Co. Meath, Ireland
Packo Ireland	Customised Stainless Steel Pressure Vessels	Ireland and Worldwide
Spectac Ltd.	Stainless Steel Specialists	Co. Louth, Ireland
Spectrum Tooling Ltd.	Stainless Steel Specialists	Galway, Ireland
Tata Steel (Corus)	Customisable Steel Products	UK
Industrial Water Equipment	Vessel and Silo Specialists	Dublin, Ireland
Moody Systems	Stainless Steel Tanks and Vessels	UK
Kent Stainless	Bespoke Stainless Steel Designs	Wexford, Ireland

Mechanical and Electrical (M&E) contractors, capable of carrying out full-scale installations of the LtAD system are outlined in **Table 10**. All contractors have proven track records and also have the ability to execute large and complex projects.

Table 10: Potential M&E Contractors for Full-Scale Installations

Mechanical & Electrical Contractors		
Company	**Expertise**	**Location**
Jones Engineering Group	Mechanical, Electrical & Maintenance	Dublin & Cork, Ireland; London, UK
JRE Group	Mechanical, Electrical & Maintenance	Clonmel, Co. Tipperary, Ireland
Dunreidy Engineering	Mechanical, Electrical & Maintenance	Kilkenny & Limerick, Ireland
Wic Contracting	Mechanical, Electrical & Maintenance	Dublin, Ireland & UK

Table 11 outlines potential automation contractors for full-scale LtAD projects. These firms will be responsible for the implementation of SCADA or similar systems.

Table 11: Potential Automation Contractors for Full Scale Installations

Automation and Process Engineering Specialists		
Company	**Expertise**	**Location**
Rockwell Automation	Automation and PLC Systems	Ireland & Worldwide
Hanley Automation	Industrial Automation	Dublin, Ireland
Shaw Automation	M&E and Automation	Antrim, N. Ireland
Design Pro.	Automation, 3D Modelling, etc.	Limerick, Ireland
Gea Ireland Ltd.	Automation, Process Engineering, Project Management	Kildare & Cork, Ireland
PM Group Ireland	Project Management	Dublin & Cork, Ireland

Table 12 outlines the potential suppliers of Combined Heat and Power (CHP) systems. These firms will be responsible for the provision of CHP systems as well as the installation and testing of such systems to ensure they are operating effectively and safely.

Table 12: Potential CHP Specialists for Full Scale Installations

CHP System		
Company	**Expertise**	**Location**
Edina	Power Generation Specialists	Ireland & UK
ENER-G	Energy Solutions	Worldwide
F4ENERGY	CHP Systems	Limerick, Ireland
Fingleton White & Co. Ltd.	CHP Systems	Portlaoise, Co. Laois, Ireland
Temp Tech.	Energy Management Systems	Limerick, Ireland

Potential providers of pumping systems for the LtAD plant are outlined in **Table 13**. Reliable pumps with the capability to create the high flow rates will be required for the system.

Table 13: Potential Pump Providers for Full-Scale LtAD Installations

Pumping & Piping Systems		
Company	**Expertise**	**Location**
Ax Flow	Pump Solution Specialists	Dublin, Ireland
Grundfos Ireland	Pump Solution Specialists	Dublin, Ireland
EPS Group	WW Pumping & treatment	Cork, Ireland
Flowtechnology Ltd.	Process Engineering & Equipment	Cork, Ireland
Apex Electrical Rewinds Ltd.	Centrifugal Pumping Systems	Dublin, Ireland
Thomson Process Equipment & Engineering Ltd.	Process Engineering & Equipment	Dublin, Ireland

Gas being produced from the digestion process will have to be purified before it can be used for power generation. Carbon dioxide (CO_2) and Hydrogen Sulphide (H_2S) will be removed from the biogas using a scrubbing system to provide the CHP unit with pure methane (CH_4) gas. See **Table 14** for companies whose expertise are in gas storage and handling.

Table 14: Potential Gas Handling specialists for full scale LtAD installations

Gas Purification and Storage		
Company	**Expertise**	**Location**
Vergas Ltd.	Gas storage systems, flaring systems,	UK
Higgins and Hewins Ltd.	Air & Gas purification systems	UK
Viessmann Ltd.	Gas Handling & Purification systems	UK

Gas and liquid monitoring equipment would be an integral part of the LtAD design, thus suppliers of monitoring equipment for pH, ORP, temperature probes and sensors are presented in **Table 15**.

Table 15: Potential Gas & Liquid Monitoring Equipment Suppliers

Gas & Liquid Monitoring Equipment Suppliers		
Company	**Expertise**	**Location**
Hach Lange	Provide solutions for WW analysis	Dublin, Ireland
Carl Stuart	WW monitoring equipment	Dublin, Ireland
Cole-Parmer	WW monitoring equipment	Dublin, Ireland

Full-Scale Plant Design & Costs: Industrial (Food & Drink) and Municipal WW

A flow-chart detailing a full-scale LtAD system for the treatment of an annual WW volume of 309,400m^3, based on the WW volumes generated in Lakeland Dairies, is presented for two WW types: (a) Municipal and (b) Industrial (Dairy Processing), see **Figure 1**. Associated equipment required to generate treated WW for release to receiving waters, based on currently available LtAD performance data and licence limits for the main wastewater pollutants, was compiled and a pricing estimate for an alternative LtAD WWTP is provided in **Table 16**.

The flow-chart (**Figure 1**) details the following treatment stages:

- *Preliminary:* involving a process of grinding and screening to produce a WW containing solids which are no larger than 6mm. A grit removal tank would be required in the municipal WWTPs, whereas this is replaced with a Dissolved Air Flotation (DAF) unit for the removal of finely divided suspended solids (SS) and particles, in a Dairy Processing plant. The induced-air flotation also aids in the removal of oil and grease is a necessity in Food & Drink industry WWT.
- Balance Tank: The purpose of the balance tank is to temporarily store the WW flow in order to equalise flow rates and mass loadings of Biochemical Oxygen Demand (BOD) and Suspended Solids (SS), for entry to the LtAD unit.
- *LtAD*: Novel LtAD unit with gas handling capabilities for treatment of WW with little to no sludge production is shown. Effluent from this LtAD treatment unit would adhere to Urban WW Directive criteria for WW discharge.
- *Gas handling & CHP unit*: A gas scrubber for removal of undesirable gases prior to CHP unit entry is included in the design. The biogas is then collected in a gas storage unit in order to ensure a continuous supply of biogas to the CHP unit. The latter is fully integrated with the digestion plant and also has remote monitoring and fault diagnosis in-built. This unit is equipped with an engine (50 kW), heat exchanger, alternator, silencer, radiator, ventilator, transformer, electricity cable and exhaust system.
- *Tertiary*: If a specific WW standard is required, above those concentrations set out in the UWWD, a tertiary treatment system using sand filtration or a similar technique for effluent polishing prior to release could be considered. It is difficult to assess the degree of tertiary treatment required at this point in the research as the WWT system design will be dependent on the WW characteristics of the source stream and on the discharge criteria that the effluent must adhere to.

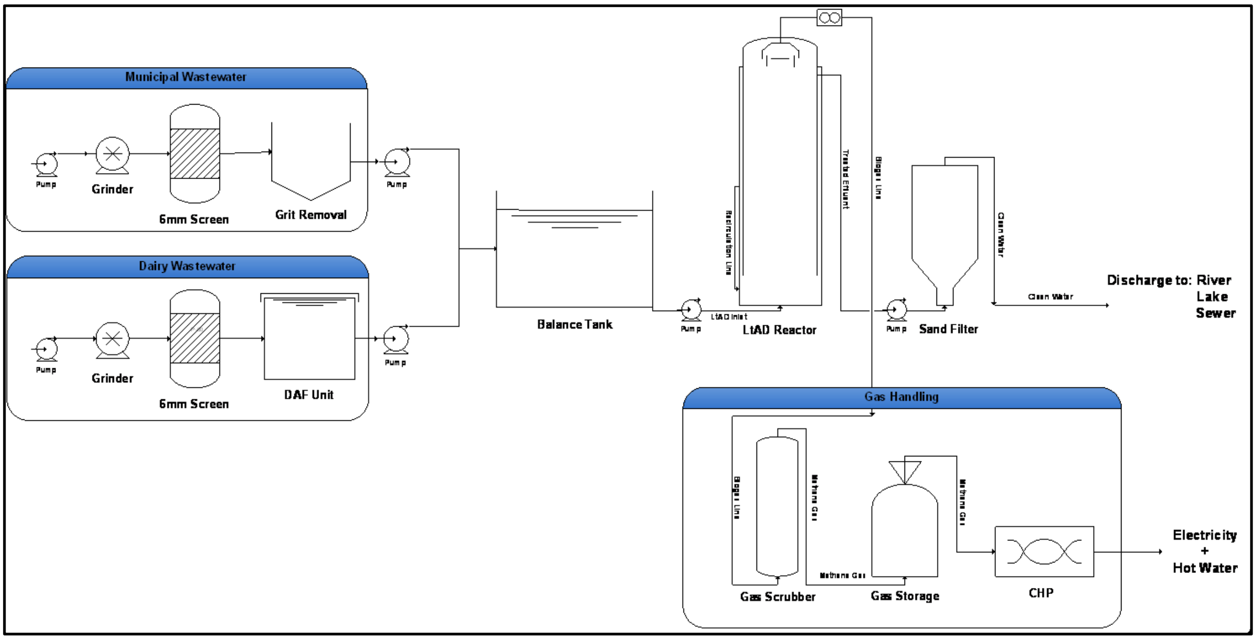

Figure 1: Flow-Chart of Proposed Full-Scale LtAD WWTP

Table 16: Calculations for a Full-Scale Set-Up of: (a) Municipal (b) Industrial (Dairy Processing) WWTP, each generating ~309,400 m³ WW annually

	(a) Municipal	*(b) Industrial*
Preliminary Treatment	**€**	**€**
Pump (80 m^3/h@1.4 bar – submersible pump)	***2,495.00***	***2,495.00***
Grinder & Fine Screens (Incl. grinder, 6mm screen & augers)	***20,000.00***	***20,000.00***
Grit Removal (500 m^3 capacity)	***155,000.00***	***Not Required***
DAF Unit (75 – 100 m^3/hour)	***Not Required***	***150,000.00***
Pump (50 m^3/h@0.8 bar – self-priming WW pump)	***2,563.00***	***2,563.00***
Balance Equalisation Tank (650 m^3 capacity)	***100,000.00***	***100,000.00***
Pump (50 m^3/h@1 bar – submersible pump)	***1,547.00***	***1,547.00***
Related Pipework: DIDF Pipe (20 Metres 150mm x 150mm)	***1,040.00***	***1,040.00***
Low temp-Anaerobic Digestion (LtAD)		
LtAD digester (volume 550m^3)	***289,995.00***	***289,995.00***
Gas monitoring equipment		
H_2S Scrubber & media (SulfaTreat dry scrubbing process based on concentrations: 500 – 1,500ppm)	***31,717.00***	***31,717.00***
Gas storage unit (200 m^3; 12 hour storage capacity)	***43,678.00***	***43,678.00***
CHP unit including auxiliaries (50 kW engine)	***97,700.00***	***97,700.00***
Liquid Phase monitoring (AnaSense® system) for:	***48,000.00***	***48,000.00***
pH, Volatile Fatty Acids, Alkalinity, Bicarbonate		
In-Vessel monitoring controller for: ORP, DO, temp., pH	***1,711.00***	***1,711.00***
4 x probes (ORP, DO, temp., pH) & related equipment	***4,602.00***	***4,602.00***
Related cabling (10m length @ €60/m)	***600.00***	***600.00***
Process monitoring		
Flowmeters x 2 (liquid)	***3,334.00***	***3,334.00***
Flowmeter (gas)	***290.00***	***290.00***
Related Pipework		
DIDF Pipe (20 metres of 150mm x 150mm)	***1,040.00***	***1,040.00***
SCADA control system & all related equipment	***10,000***	***10,000***
Tertiary Treatment (if required)		
Pump (50 m^3/h@0.8 bar – self-priming WW pump)	***2,563.00***	***2,563.00***
Sand filter (ASTRASAND® Paques filter, 53 m^3/h)	***75,000.00***	***75,000.00***
Related Pipework: DIDF Pipe (20 m of 150mm x 150mm)	***1,040.00***	***1,040.00***
Total CAPEX (€) estimate (ex. Tertiary treatment):	***815,312.00***	**810,312.00**
Total CAPEX (€) estimate (inc. Tertiary treatment):	**893,915.00**	**888,915.00**
Income:		
Potential biogas (methane) generation (m^3/year)[note 1,2]	*129,948*	*129,948*
Calorific Value of biogas: 6kWh/m^3 (kWh)[note 2]	*779,688*	*779,688*
Total MWh/m^3 available for use (MWh)	*779.69*	*779.69*
Power for electricity usage (33%) (MWh)[note 3]	*257.30*	*257.30*
Potential revenue (€) from electricity (€130/MWh)[note 4]	***33,449.00***	***33,449.00***
Power for heat usage (50%) (MWh)[note 3]	*389.85*	*389.85*
Kerosene per annum (L/y)[note2]	*37,684.92*	*37,684.92*
Potential revenue (€) from kerosene (0.87/L)[note 4]	***32,785.88***	***32,785.88***
Total potential revenue (€) (based on electricity & kerosene)	***66,234.88***	***66,234.88***

[1]Methane (CH_4) yield efficiency values were derived from the established stoichiometric value of 0.35L (CH_4 produced) per gram of COD removed (0.35m^3/kg COD removed), equaling 100% efficiency as previously reported (Lawrence and McCarthy, 1969). For the purpose of this exercise an efficiency of 80% is used; thus 309,400m^3 low strength WW generates 129,948m^3 CH_4/year (309,400m^3*1.5kg COD*0.35 m^3 CH_4*80% efficiency); [2]The calorific value of biogas c. 6 kWh/m^3 is equivalent to 0.58L kerosene (Pathak et al., 2009); thus LtAD treatment of industrial or municipal low strength WW producing 309,400m^3 WW per year producing 129,948m^3 available biogas generates 37,684.92L/year kerosene (129,948m^3*50%*0.58L);
[3]Efficiency for CHP generation from biogas (%) (Pöschl et al., 2010);
[4]Prices based on current market value (kerosene) and projected REFIT (electricity) prices from CHP AD (www.dcenr.gov.ie).
Notes: Where quotes were obtained in sterling, an exchange rate of: €1:£0.87 were used for conversion (www.xe.com); the LtAD manufacturing quotation of €289,995.00 is a basic price for supply of materials and manufacture on-site.

Full-Scale Plant Retrofit Scenario

A detailed schematic of the currently used conventional aerobic (CA) WWT process in Lakeland Dairies is shown in **Figure 2**, highlighted as "Outdated System" for the purpose of this report. The introduction of the novel LtAD treatment system, i.e. "LtAD and Biogas System" as an alternative to the currently used system is shown. The "LtAD and Biogas System" would eliminate the need for aeration, clarification, sludge thickening and dewatering, as well as final sludge disposal. The biogas generation using the LtAD process would provide a valuable asset to industry as a saleable resource. Greater details on the processes occurring in the "LtAD and Biogas System" was provided under the "Full-Scale Plant Design" description earlier in this section.

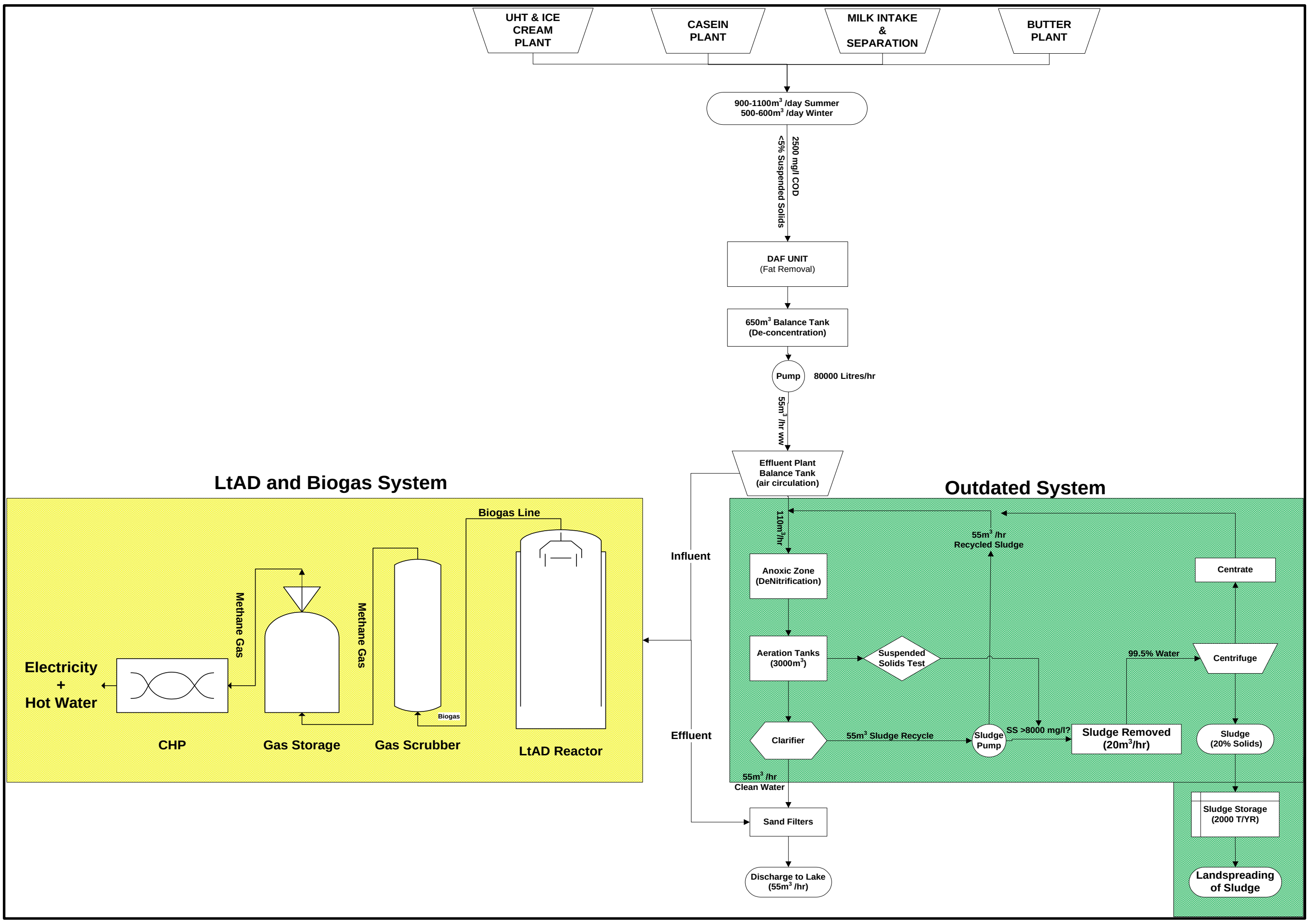

Figure 2: Lakeland Dairies WWT Flow-Chart – Retrofit Scenario

A detailed CAPEX and OPEX analysis, if the novel LtAD WWT system was used to retrofit a plant currently using either CA or mesophilic AD, is provided in **Table 17.** All figures are based on a case study performed using confidential information received from Lakeland Dairies which produce approximately 309,400m^3 WW annually from their dairy operations. Costings are based on the schematic representations of the WWT processes shown in **Figure 2**, which are detailed in **Figure 3(a) –3(c)** in the pages which follow.

Table 17: Calculations for Set-Up of a Full-Scale WWTP, generating approximately 309,400 m^3 Low Strength WW annually

	LtAD (Figure 3a)	***Conventional Aerobic (Figure 3b)***	***Mesophilic AD (Figure 3c)***
	€	**€**	**€**
Effluent Preliminary Treatment	Common	Common	Common
Screening			
Grit removal			
DAF unit			
Balance/Equalisation Tanks	Common	Common	Common
Anoxic Zone (Denitrification) (2 x 700m^3)	Not required		Not required
CAPEX		***790,000.00***	
OPEX		***22,582.00***	
Aeration tank (3000 m^3)	Not required		Detailed below (post-AD)
CAPEX inc. air pump		***1,580,000.00***	
OPEX		***22,582.00***	
2 x Settlement tanks/clarifiers (1000 m^3)	Not required		Detailed below (post-AD)
CAPEX inc. air pump		***465,000.00***	
OPEX		***34,408.00***	
Anaerobic Digestion (AD), Biogas & monitoring		Not required	
LtAD CAPEX (digester volume 550m^3)	***289,995.00***		***289,995.00***
OPEX inc. Labour	***24,000.00***		***24,000.00***
Gas Conditioning & Treatment (CAPEX)			
H_2S Scrubber (SulfaTreat dry scrubbing process based on concentrations: 500 – 1,500ppm)	***31,717.00***		***31,717.00***
CHP unit including auxiliaries (50 kW engine)	***97,700.00***		***97,700.00***
Gas storage unit (200m^3; 12h storage capacity)	***43,678.00***		***43,678.00***
Liquid, In-Vessel & Processing Monitoring Equipment (detailed in P.17)			
AnaSense®, in-vessel monitoring, 4 x probes & related equipment	***54,313.00***		***54,313.00***
Flow meters (liquid)	***3,334.00***		***3,334.00***
Flow meters (gas)	***290.00***		***290.00***
Related Cabling (10m of outside cabling)	***600.00***		***600.00***
Related pipework (20m of 150mm x 150mm DIDF pipe)	***1,040.00***		***1,040.00***
SCADA control system & all related equipment	***10,000***		***10,000***
Reduced volume post-AD aeration tank (750 m^3)	Not required	Detailed above	
CAPEX inc. air pump			***395,000.00***
OPEX			***14,041.00***
Reduced volume post-AD settlement tanks/clarifiers (500m^3)	Not required	Detailed above	
CAPEX inc. air pump			***155,000.00***
OPEX			***19,954.00***

	LtAD (Figure 3a)	***Conventional Aerobic (Figure 3b)***	***Mesophilic AD (Figure 3c)***
	€	**€**	**€**
Further treatment of effluent post-sludge removal	Common	Common	Common
Sand filters			
CAPEX			
OPEX			
Sludge Treatment	Not required		
Centrifuge for dewatering			
CAPEX		***207,000.00***	***90,000.00***
OPEX		*Detailed below*	Detailed below
Volume of sludge to be treated/year (m^3)		120,000	30,000
Operation time/per week (h/w)		80.00	33.33
Working weeks/per year (w/y)		50	50
Hydraulic loading rate (m^3/h)		30	18
DS-Concentration inlet (%DS)		0.5	0.5
DS-Concentration outlet (%DS)		18	18
Polyelectrolyte system, installation, pumps, commissioning		68,000.00	68,000.00
*Installation, sludge pumps, cabling, piping, conveyors for dewatering sludge not included in prices			
Operating Costs (OPEX)			
Energy Costs			
Energy cost € kWh		0.15	0.15
Energy consumption kW/h		21.1	18
Annual energy costs		***12,660.00***	***4,500.00***
Polymer Costs			
Polymer consumption (kg/tDS)		8	8
Polymer cost (kg) (€5)		***123,760.00***	***30,940.00***
Labour Costs*			
Labour time (h/w)		20	5
Labour cost (per hour)		22.00	22.00
Annual operating cost		***22,000.00***	***5,500.00***
Maintenance Costs			
Maintenance (Labour & material)		***3,105.00***	***3,105.00***

		LtAD (Figure 3a)	Conventional Aerobic (Figure 3b)	Mesophilic AD (Figure 3c)
		€	€	€
Phosphorous Reduction, Liming & Land spreading		Not required		
OPEX				
Aluminium Sulphate for P reduction (1.5kg/1000kg)			***9,282.00***	***9,282.00***
Aluminium Sulphate cost (€20/kg)				
Lime consumption (1kg/5kg 20%S)				
Lime cost (€0.13/kg)			***52,000.00***	
Land spreading spend per wet tonne of sludge (€65/t; 2,000t per annum)			***130,000.00***	
Revenue from sludge sold as seed for bioreactors		**-6,000.00**	**n/a**	**-6,000.00**
Total CAPEX (% reduction using LtAD)		***556,667.00***	***3,042,000.00 (82)***	***1,172,667.00 (53)***
Total OPEX (% reduction using LtAD)		***18,000.00***	***432,379.00 (96)***	***105,322.00 (83)***
Income: Potential biogas (methane) generation *note 1*	m^3/y	*129,948*	n/a	*129,948*
Biogas required for heating AD system	m^3/y	*0*		*129,948 (100%)note 1*
Biogas (methane) available for electricity/heat	m^3/y	***129,948***		***0***
Calorific value of biogas: 6kwh/m^3 note 2	kWh	*779,688*		*0*
Total mWh/m^3 available for use	MWh	*779.69*		*0*
Power for electricity usage (33%) note 3	MWh	*257.30*		*0*
Potential revenue (€) from electricity generation note 4	**€130/MWh**	***33,449.00***		***0***
Power for heat usage (50%) note 3	MWh	*389.85*		*0*
Kerosene per annum note 2	L/y	*37,684.92*		*0*
Potential revenue (€) from kerosene note 4	**€0.87/l**	***32,785.88***		***0***
Total potential biogas revenue (€) from low-strength WW	€	***66,234.88***	**0**	***0***

[1]Methane (CH_4) yield efficiency values were derived from the established stoichiometric value of 0.35L (CH_4 produced) per gram of COD removed (0.35m^3/kg COD removed), equaling 100% efficiency as previously reported (Lawrence and McCarthy, 1969). For the purpose of this exercise an efficiency of 80% is assumed; thus 309,400m^3 low strength WW generates 129,948m^3 CH_4/year (309,400m^3*1.5kg COD*0.35 m^3 CH_4*80% efficiency); Mesophilic AD treatment of such low strength WW would be unfeasible as it's thought that 100% of the biogas produced would need to be reused for heating the bioreactor to mesophilic temperatures, thus leading to no excess biogas being produced. LtAD is however suitable for use with both low and high strength WW as the bioreactor does not require heating to temperatures >15°C.

[2]The calorific value of biogas c. 6 kWh/m^3 is equivalent to 0.58L kerosene (Pathak et al., 2009); thus LtAD treatment of industrial or municipal low strength WW producing 309,400m^3 WW per year producing 162,435m^3 available biogas generates 37,684.92L/year (129,948m^3*50%*0.58L kerosene) & mesophilic AD producing 84,466m^3 available biogas generates 24,495L/year (105,582.75m^3 *50%*0.58L kerosene)

[3]Efficiency for CHP generation from biogas (%) (Pöschl et al., 2010);

[4]Prices based on current market value (kerosene) and projected REFIT (electricity) prices from CHP AD (www.dcenr.gov.ie).

Notes: Where quotes were obtained in sterling, an exchange rate of: €1:£0.87 were used for conversion (www.xe.com); the LtAD manufacturing quotation of €289,995.00 is a basic price for supply of materials and manufacture on-site.

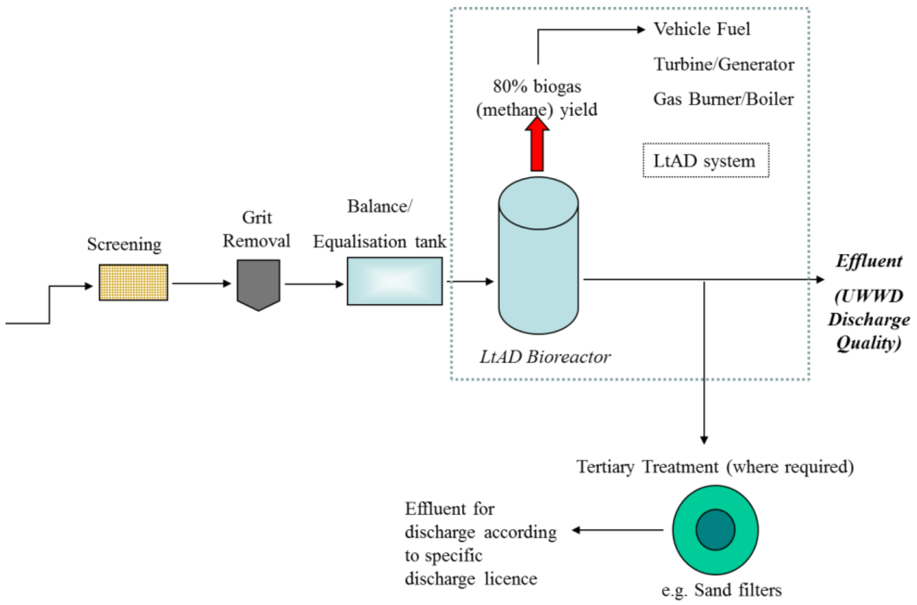

Figure 3(a): Proposed LtAD WW Treatment Process

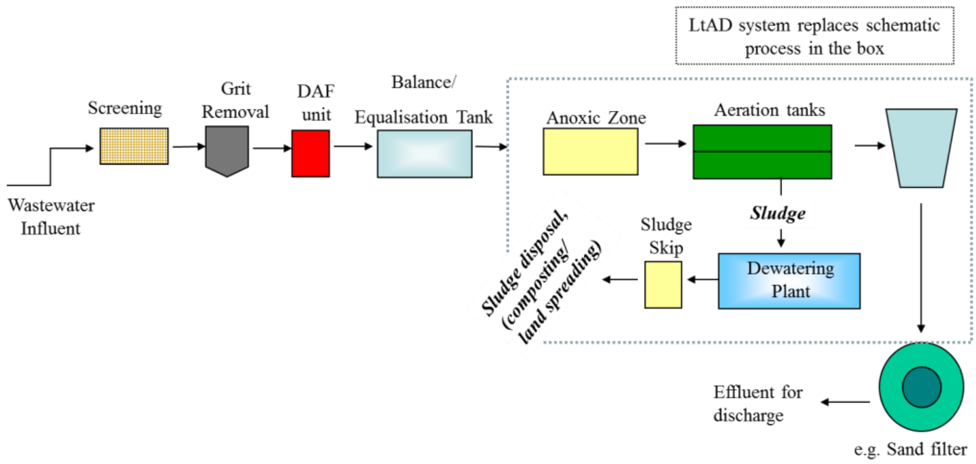

Figure 3(b): ***Conventional Aerobic (CA) WW Treatment Process***

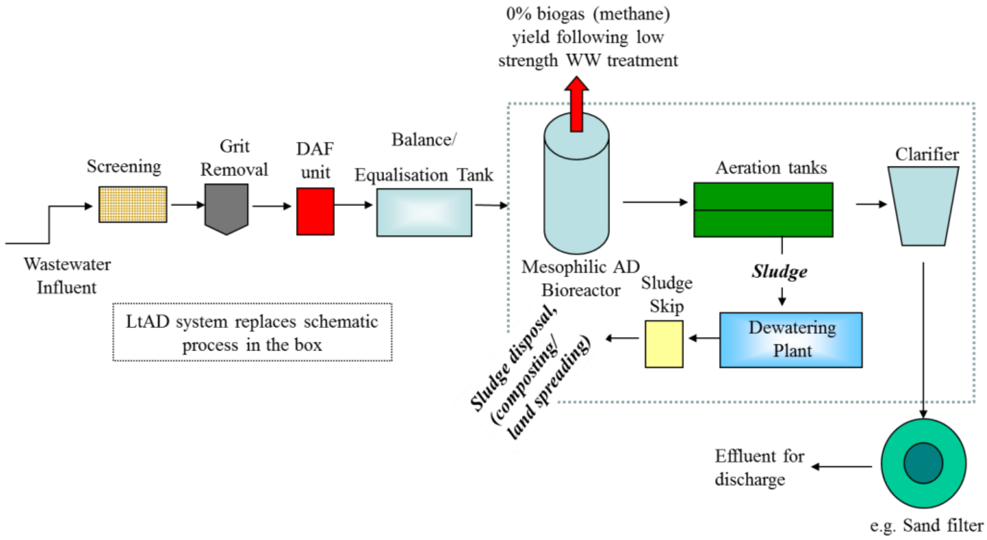

Figure 3(c): Mesophilic High-Temperature AD WW Treatment Process

Appendix 1: Database of UK & Ireland Potential End-Users

See accompanying excel spread sheets entitled “Irish Food & Drink Industry Market ” and “UK Food & Drink Industry Market” which contain information relating to potential UK and Irish market end-users for the LtAD technology. A thorough analysis was carried out in the case of Ireland and a representative sample of industries is presented in the case of the UK.

Appendix 2: Short Review of Food & Drink Industry Wastewater

In order to obtain a clear picture of the characteristics of the WW of interest, a short literature review was carried out for the purpose of assessing the WW generated from each of the main sectors: (a) Municipal and (b) Food & Drink Industry, i.e. Brewery & Distillery, Food Production and the Dairy industry (incorporating: Milk Treatment & Processing and Manufacture of Dairy Products).

(a) Municipal

There is no 'typical' wastewater composition but guideline data on the composition of untreated domestic wastewater as found in wastewater-collection systems (in the US) are shown in **Table 18** below.

Table 18: Typical Composition of Untreated Municipal WW (Metcalf & Eddy, 2004)

Parameters	Concentration Range (mg/L)
Chemical oxygen demand (COD) total	260-900
Biochemical Oxygen Demand (BOD) total	120-380
Total suspended solids (TSS)	120-370
Total Phosphorous (TP)	4-12
Total Kjeldahl N (TKN)	20-45

(b) Foods & Drink Industry

Brewery & Distillery

In the Food & Drink industry, the Brewery sector holds a strategic economic position with the annual world beer production exceeding 1.34 billion hectolitres in 2002 (FAO Source, 2003). Thus, it is no surprise that beer is the fifth most consumed beverage in the world behind tea, carbonates, milk and coffee and it continues to be a popular drink with an average consumption of 23 litres/person per year (Fillaudeau, L. et al, 2006).

The Brewery sector consumes and produces significant volumes of process water and wastewater, respectively, resulting in water:beer:wastewater ratios ranging from 4-11:1:2-8m^3 for each m^3 of beer produced (Driessen and Vereijken, 2008). Similarly, significant volumes of wastewater effluent is generated from alcohol distilleries, in fact it has been reported that on an average 8–15 L of effluent is generated for every litre of alcohol (Saha, N.K. et al, 2005). As a result of this high wastewater yield, water and WW management in breweries remains a critical and practical problem. The desire to keep disposal costs low whilst complying with more and more stringent guidelines for WW effluent release requirements is a very difficult balance (Fillaudeau, L. et al, 2006). The average composition of brewery WW is shown in **Table 19**.

Table 19: Brewery Sector WW Characteristics (A. Alvarado-Lassman, et al., 2008)

Parameters	Concentration (mg/L)
pH (no units)	10.0
COD total	2083
COD soluble	1726
BOD total	1375
COD-BOD ratio (no units)	1.51
TSS	750
Total Phosphorous (TP)	4.8
Total Kjeldahl N (TKN)	116
Ammonium-Nitrogen (NH_4^+-N)	13.3

Food Production

It is difficult to give a general composition of WW generated from the Food Production industry as the number of raw materials, processes and types of products involved in the industry are enormous. It seems that most types of WW require BOD reduction because they contain organic matter represented by starch, sugars and protein. In addition, WW is discharged in different forms which is dependent on the production system. WW characteristics of effluent from Irish Food Production industries can be found in the accompanying spread sheet, referenced in **Appendix 1**.

Dairy – both Milk Treatment & Processing and Manufacture of Dairy Products

Water is used throughout all steps of the Dairy sector including cleaning, sanitization, heating, cooling and floor washing, thus the requirement for water is huge. In fact, amongst the food industries, Dairy is the most polluting in terms of volume of effluent generated as well as in terms of its characteristics, generating about 0.2-10 L of effluent per litre of processed milk (Vourch, M. et al., 2008).

The wastewaters generated are rich in biodegradable organics (BOD), COD and nutrients (Ramasamy & Abbasi, 2000) – see **Table 20**. High levels of dissolved or total suspended solids (TSS) including fats, oils and grease are also present which require attention prior to disposal. In fact, milk has a BOD value 250 times greater than that of sewage, see values for milk products in **Table 21**. If not treated, they cause gross pollution of land and water with their high BOD and COD values. But they also have the potential to supply carbon in a form that anaerobic microorganisms can convert into methane (Franklin, 2001). This opens up the possibility of generating clean fuel (methane) with concomitant pollution control.

In Ireland, wastewaters resulting from the food industry typically contain elevated levels of nitrogen and phosphorus before treatment. A study using Dairy Food industry WW reported the following WW characteristics: 1008 - 1757 mg COD/L; 30.1 - 62 mg NH_4-N/L and 26.7 - 57 mg P/L (Mulkerrins, D. et al, 2004).

Table 20: Dairy Sector WW Characteristics (Sarkar, B. et al., 2006)

Parameters	Concentration (mg/L)
pH (no units)	5.5-7.5
TSS	250-600
Turbidity (NTU)	15-30
TDS	800-1,200
COD	1,500-3,000
BOD	350-600

Table 21: Reported BOD and COD Values for Typical Dairy Products (Wang & Howard, 2004)

Product	BOD (mg/L)	COD (mg/L)
Whole milk	114,000	183,000
Skim milk	90,000	147,000
Butter milk	61,000	134,000
Cream	400,000	750,000
Evaporated milk	271,000	378,000
Whey	42,000	65,000
Ice cream	292,000	-

Appendix 3: Information to Support LtAD Advantages

"A comprehensive literature and market review for assessment of competing technologies to confirm specific advantages of system in CAPEX, OPEX and sludge reduction terms."

The specific advantages of the LtAD system in terms of CAPEX, OPEX and sludge reduction terms was presented earlier in this report using confidential information from Lakeland Dairies in Co. Cavan as a representative example of a Dairy Processing industry. The costings are based on the retrofit of the existing conventional aerobic WWT process on-site (albeit industrial or municipal WWT), this costly treatment system generates large quantities of sludge which subsequently require thickening, dewatering and disposal.

Assessment of competing technologies

Although anaerobic digestion (AD) is now an established and proven technology for the effective treatment of a vast range of wastewaters, the majority of full-scale applications and research has been centred on AD within the mesophilic (25-45°C) or thermophilic (45-65°C) temperature ranges. However, the majority of industrial effluents are not discharged at temperatures in the ranges required for mesophilic or thermophilic microorganisms. Thus, one of the main advantages of psychrophilic AD is its ability to treat WW at temperatures of <20°C, i.e. temperatures at which effluent is actually discharged. As a result, psychrophilic AD is cost-efficient as the need to heat influent WW or to direct AD-produced energy back into bioreactor heating, is essentially eliminated.

It must be stressed that currently available conventional AD techniques, operating at thermophilic, mesophilic or psychrophilic temperatures, produce effluent with suspended solids and non degraded carbon, thus there is a need for aerobic post-treatment for residual COD and BOD removal. However, the novel LtAD technology developed at NUIG is not a conventional AD process. It operates at temperatures <20°C using psychrophilic microorganisms but the process also involves an unique filtration feature in the reactor design which provides an enhanced technology to recognised AD systems. Basically, the performance of the novel LtAD technology is superior to established AD systems because: (a) the effluent produced is of better quality; (b) there is no need for aerobic post-treatment of effluent; (c) it can run at lower temperatures, thus improving biogas yield, and (d) can reduce P to UWWD standard levels, which is an unique feature of the LtAD process. If lower emission limits than those set by the UWWD are required, an optional tertiary treatment system such as a sand filter or an alternative polishing system could be employed post-LtAD treatment. Such an option is incorporated into both a new plant and a retrofit scenario, as shown in **Table 16** and **17** respectively.

The target markets for the novel LtAD technology are those which produce low strength WW, i.e. municipal and industrial sources (Food & Drink industry sectors such as Brewing & Distilling, Dairy Processing etc.). One such target industry - Dairy Processing, is generally considered to be the largest source of food processing WW in many countries and since dairy wastewaters are highly biodegradable they can be effectively treated with biological WWT systems. However, LtAD competing technologies, such as mesophilic AD, are not applicable to the low strength WW market due to the low available carbon content of such wastewaters which make them uneconomically feasible to a higher temperature AD process. The conventional aerobic (CA) alternative generates significant quantities of sludge during the treatment process which in turn requires thickening, dewatering and final disposal. As a result, the novel LtAD technology is targeting a market where currently a sustainable treatment solution does not exist. A synopsis of the advantages and disadvantages of alternative technologies are detailed in **Table 22**.

Table 22: Advantages & Disadvantages of Existing WWT Techniques

	Advantages	Disadvantages
Conventional Aerobic (CA)	- Simple, well-known process.	- High dewatering and disposal costs associated with remaining sludge - Odorous emissions - No significant pathogen removal at cryophilic temperatures - High associated CAPEX and OPEX
Mesophilic AD	- Widely used process - Production of a biogas, thus low operational costs - Low odorous emissions - Less physical space is required (compared with CA) - Reduction in sludge produced (compared with CA) so sludge dewatering and disposal costs are lowered.	- High CAPEX - Energy needs to be supplied (approx. 35% of biogas produced) to power AD process) so all the biogas generated is not available for resale - Post-aeration step required - High dewatering costs associated with remaining sludge which requires final disposal - Industrial effluent needs to be heated to optimum mesophilic temperatures prior to treatment

It is clear from our market review that there is an excellent commercial opportunity for an Irish spin-out company using the novel LtAD design for low-strength WWT. As regards industrial WW production in Ireland alone, the Dairy Processing industry generates approximately 13 million m^3 WW for treatment annually. Operational costs for the treatment of such volumes using the most commonly used technique – CA, are estimated at €18.2 million per annum (based on Lakeland Dairies OPEX of €1.40/m^3 wastewater). An alternative Food & Drink industry sector - the Irish Brewing industry, is the 33rd largest beer producer in the world and generates over 0.8 million m^3 of beer per annum (IBA report, 2010), which equates to approximately 4.8 million m^3 WW for treatment annually (Connaughton, et al. 2006) at an estimated annual spend of €6.72 million for the industry. The novel LtAD technology presented herein can reduce these spends by up to 96% compared to CA and by up to 83% when mesophilic AD is the technique employed, see detailed calculations provided earlier in the report for a retrofit scenario in **Table 17**. The comprehensive review of the WWT processes currently employed in the Food & Drink industry in both Ireland and the UK (see **Appendix 1**) indicates that CA and mesophilic AD are the predominantly used WWT techniques; both technologies have high capital and operational costs (particularly in the case of CA) and produce a final sludge product for disposal which currently costs in the range of €60 - €90 per tonne for land-spreading or composting in Ireland (based on local enquires), and between $100 - $500 per tonne for sludge handling and disposal in the USA (Fabiyi et al., 2007). The use of the unique LtAD technology essentially eliminates the need for sludge handling and disposal as only a small amount of sludge is produced when compared to alternative aerobic technologies. In addition, the small amount of sludge which is produced has a market value associated with it as an inoculum for other AD reactors. **Table 23** synopsises the major differences between the novel LtAD technology and alternative technologies.

Table 23: Comparison of Novel LtAD with Alternative Technologies

	Novel LtAD	CA	Mesophilic AD
Operational Temperature (°C)	<20	n/a	25-45
Sludge generated (kg sludge/kg BOD removed)	0.05	0.5	0.1
Sludge dewatering equipment required	×	√	√
Aeration system required	×	√	√
Chemicals required for P attenuation	×	√	√

Discussions with relevant contacts in the Food & Drink industry, i.e. Kerry Ingredients Ltd. (Dr. Sean Pender), Lakeland Dairies (Mr. Rory Farrell) and Glanbia, as well as plant managers of municipal WWTPs regarding issues they experience with their currently used WWT processes, provided excellent feedback on the needs of potential customers. Issues raised such as: (a) high capital and operational costs and (b) the generation of sludge requiring further treatment and disposal, are easily overcome with the retrofit of the novel LtAD system into a plant's treatment process. During these discussions, the PI highlighted that the proposed LtAD technology eliminates the need for sludge handling, treatment, final disposal and in turn generates an effluent which adheres to the UWWD discharge standards in a simple design suitable for a range of low strength WW.

The generation of a valuable biogas product which can in turn be used to generate electricity and heat is a common feature of all AD systems. However, the added advantage of LtAD is that *all* of the biogas generated can be converted to useful products, there is no loss of yield for digester heating since the low temperature psychrophilic system operates at an ambient temperature of <20°C. The LtAD process facilitates the resultant electricity to be sold to the National Grid under the Renewable Energy Feed in Tariff (REFIT) scheme at a set price (Joint Committee on Communications, Energy and Natural Resources report, 2011), the heat generated using CHP can subsequently be used in other areas of the plant, i.e. heating buildings, offices or to generate hot water steam for washing vessels, etc. Such uses are otherwise being fuelled by external sources such as kerosene, which costs the plant a significant amount of money. Through this project, the strengths of the LtAD technology can be demonstrated directly to industrial contacts using a pilot-scale LtAD system which was located on-site at both Kerry Ingredients Ltd. and Lakeland Dairies during this project.

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